Identification of transport-dominated large-scale structures in turbulent wall-bounded flows using a Characteristic DMD

Coherent structures in turbulent flows are known as organized motions possessing spatial and temporal coherence, having a prominent contribution to the turbulent kinetic energy and mass and momentum diffusion. Therefore, they come with large desirable or undesirable effects in the flow, such as better mixture or more drag. Despite large number of studies carried out in the last decade to understand their physical properties, there is still limited consensus in the scientific community on how to define these structures, what they physically look like, how long they live and how their length scales depend on Reynolds numbers. On the other hand, uncertainties like what they feed on, how their regeneration mechanism works and how they interact with each other, as well as with near wall turbulence, are yet to be unraveled.

The main objective of this study is to extract low dimensional subspaces out of highly complex turbulent flow fields, which meet our intuitive understanding of large coherent structures. In particular the structures living in these subspaces shall have a long lifetime, live on large scales and travel with a certain group velocity. To this end, a temporal sequence of state vectors from DNS and time-resolved measurements, will be transformed such that we find persistent dynamical modes on a hypersurface traveling along its normal in space and time on a moving frame of reference. The transformation is in form of a rotation in space and time. A Dynamic Mode Decomposition (DMD) will be carried out on the transformed data to capture the modes possessing small decay or growth rates. Reconstruction of the candidate modes along the normal to the hypersurface and transforming them back to physical space gives the low rank model of the flow. The algorithm which is known as Characteristic DMD (CDMD, Sesterhenn & Shahirpour 2019), will be next applied to the residual of the flow field looking for the next largest group velocity. This gives a hierarchy of structures. In practical terms, we aim to separate large coherent structures, coherent structures, and an uncoherent remaining rest. The method will be applied to two canonical turbulent flows. The resulting structures will be tested against physical evidence, by verifying that the footprints of large-scale coherent structures in premultiplied energy spectra can be reproduced by them. Each group of structures will be studied separately in terms of their lifetimes, spatiotemporal evolution, length scales and turbulent properties.

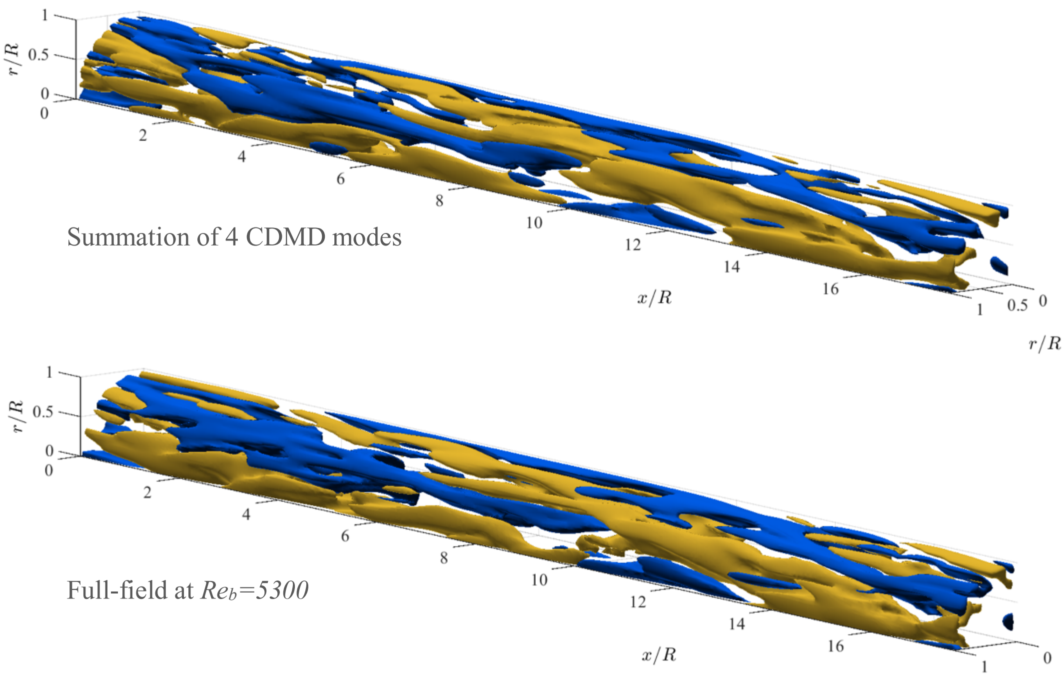

Figure 1. Summation of four dynamical modes reconstructed along the characteristics (top), compared against the full-field in the DNS of turbulent pipe flow (bottom) at $Re_b=5300$. The modes have been extracted on a moving frame of reference with group velocity of $U_g = 0.85\ U_b$. Regions of yellow and blue correspond to streamwise velocity fluctuations ($\pm\ 0.1\ U_b$). Simulations are carried out using nsPipe code (Lopez et al. 2019).